BELLCOMM, INC.
1100 Seventeenth Street, N.W. Washington, D.C. 20036

SUBJECT: Families of 1977 Triple-Planet Flybys - Case 233

DATE: June 6, 1967

FROM: A. A. VanderVeen

ABSTRACT

Four launch windows spanning one-hundred-sixty days were found to exist for ballistic triple-planet (Venus-Mars-Venus) flybys in late 1976 and early 1977. Associated with each ten-day to two-week launch window are early and late arrivals at earth.

The characteristics of all eight distinct families of trajectories are briefly discussed to show that the 1977 triple-planet flyby should be considered a strong candidate mission for our planetary exploration program.

(NASA-CR-154355) FAMILIES OF 1977 TRIPLE-PLANET FLYBYS (Bellcomm, Inc.) 13 p

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MEMORANDUM FOR FILE

Introduction

Several families of all-ballistic triple-planet flybys (Earth-Venus-Mars-Venus-Earth) have been found for launch dates in late 1976 and early 1977. As a composite, these families offer a mission launch opportunity spanning one-hundred-sixty days with trip durations ranging from under six-hundred to over eight-hundred days. While their data are, as yet, incomplete, preliminary results indicate that the 1977 triple-planet should be considered as a strong candidate mission for our planetary exploration program. A more complete and detailed analysis of this mission will be presented in a later memorandum after additional data has been acquired.

General

The one-hundred-sixty day opportunity is comprised of four launch windows, which may be designated A, B, C, and D. Corresponding to each of these windows are two distinct families of trajectories, one arriving at earth some seventy days earlier than the other. Let the arrivals be distinguished by types 1 and 2, so that the eight primary families of purely ballistic triple-planet flybys found thus far may be uniquely classified for reference purposes.

Figure 1 shows schematically all eight distinct families by their dates of planetary encounter. Table 1 gives the trajectory parameters associated with the beginning and end of each launch window. It should be understood here that the window definition is not all-inclusive for each family, but rather is merely represented by data obtained thus far. The families are listed in the order of increasing departure date with early and late earth arrivals tabulated in pairs. It can be seen that a trade-off exists between entry velocity and trip duration within each launch window. It may also be noted that distant passages of Venus at its second encounter are associated with the early arrival type trips. In fact, the 1976 dual-planet flyby reported in Reference 1 is a special case of the class A-1 triple-planet flyby, whose earth return date has been advanced fifteen or twenty days, forcing the Mars-to-earth legs out of Venus' sphere of influence.

The earth departure declinations are also given in Table 1 for each family of trajectories. While the class B-1 family offers a relatively "comfortable" mission in terms of injection velocity, entry velocity, and trip duration, a plane change would be required out of earth parking orbit in order to acquire the outbound asymptote with its high declination. A curve (Figure 2) has been included to show the minimum plane change required as a function of launch azimuth.

Figure 3 shows a typical mission profile for the family of class B-2 trajectories. This profile was chosen to illustrate the symmetry of the 1977 triple-planet flyby opportunity. It may be observed that each of the legs have transfer angles close to 180°; i.e., all transfers within this family are bounded by the steep velocity gradients of the 180° transfer ridges, which are caused by the mutual inclinations of the planets' orbits. The symmetry property, along with the condition that ballistic passages at the terminal planets' must exist, requires that the elliptical transfers depart and arrive almost tangentially to the planetary orbits, which condition, in turn, results in trajectories having low terminal velocities. The early return families have Venus-earth legs which encounter earth's orbit non-tangentially, and hence, the earth arrival velocities are much higher. The trajectories of each class of family have symmetry with respect to their Venus-Mars-Venus transfers. This important property results in trajectory profiles whose maximum and minimum radial excursions are bounded by the orbits of Mars and Venus, respectively; thus, the asteroid belt is avoided.

Figures 4, 5, and 6 provide more detailed information regarding the asymptotic velocities, encounter dates, and passage radii associated with family B-2 trajectories. In this family a nominal trajectory was selected for purposes of study standardization within Bellcomm. It's salient features are listed in Table 2.

Figure 7 illustrates the trade-off that exists between "backing up" the launch date and providing a bend-angle delta-V at the first passage of Venus (to provide a 1.1 radii clearance) for the class C-1 family. It is noted that beyond JD 244 3200 both the injection delta-V and the passage delta-V increase rapidly with launch date.

The high earth departure velocities associated with the D-class trips place these families in a categoty of lesser interest than the others. However, comparatively short trip durations may be had, if contingencies force the launch date to slip into this latest window.

Summary

A one-hundred-sixty day launch opportunity comprised of four windows, each having at least ten days duration at earth, exists in late 1976 and early 1977 to fly by Venus, Mars, and Venus ballistically. Early and late returns to earth are possible for each launch window, but higher entry velocities accompany the early returns.

Missions launched during the first available window are of long duration; associated with the second window are high earth departure declinations; passage-distance delta V's will probably be required for missions of the third window; and high departure velocities (probably prohibitive) are required for the late launch missions. So a clear-cut choice of a "best" mission is not immediately apparent. However, it is quite likely that small impulses at the flyby planets' can be made in order to obtain a trajectory that possesses the best properties of each family and thereby achieve additional mission flexibility.

Asteroid protection is of minimum concern for this mission, since the trajectories do not extend beyond Mars' orbit.

1013-AAV-pdm

A. A. VanderVeen

Attachments
  Reference
  Figures 1-7
  Tables 1 and 2

REFERENCE

1. "Existence of a Favorable 1976 Dual-Planet Ballistic Flyby," by H. S. London and A. A. VanderVeen, dated February 14, 1967.

PLANETARY ENCOUNTER DATES FOR THE 1977 TRIPLE-PLANET FLYBYS

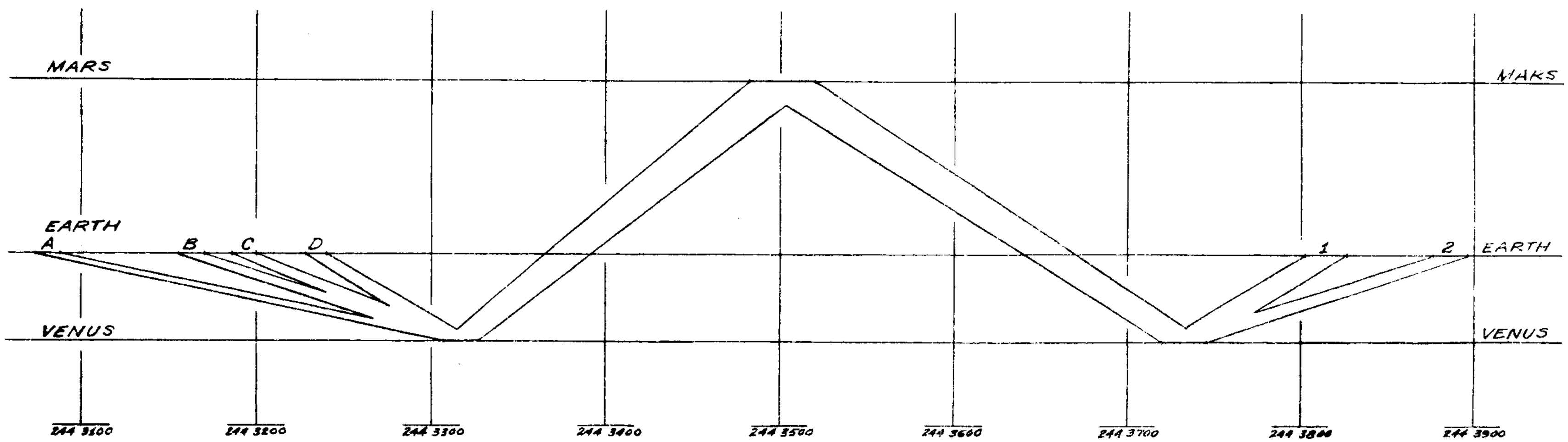

FIG. 1 LAUNCH AND ARRIVAL DATE SCHEMATIC DIAGRAM

TABLE 1

CHARACTERISTICS OF 1977 TRIPLE PLANET FLYBY FAMILIES

CLASS (Launch Window -- Return Type)	EARTH DEPART			FIRST VENUS PASSAGE			MARS PASSAGE			SECOND VENUS PASSAGE			EARTH ARRIVE	
	DATE	V_∞	DECLIN.	DATE	V_∞	R_p	DATE	V_∞	R_p	DATE	V_∞	R_p	DATE	V_∞
A-1	3074	.216	11.8	3307	.214	1.061	3493	.158	2.501	3726	.321	4.158	3810	.411
	3088	.239	18.9	3324	.262	1.913	3515	.148	2.100	3743	.231	5.275	3826	.343
A-2	3074	.215	11.8	3309	.215	1.022	3511	.147	2.176	3739	.243	1.053	3880	.156
	3088	.236	18.9	3324	.259	1.912	3517	.148	1.875	3746	.227	1.586	3896	.146
B-1	3155	.218	60.2	3307	.215	1.204	3507	.149	2.384	3735	.264	6.428	3820	.364
	3165	.214	59.0	3315	.223	1.127	3511	.147	2.157	3741	.237	5.829	3825	.344
B-2	3160	.213	59.6	3311	.215	1.194	3509	.147	2.348	3738	.247	1.007	3878	.159
	3170	.219	58.6	3318	.235	1.017	3514	.146	1.794	3740	.229	1.042	3896	.147
C-1	3186	.178	-35.7	3307	.217	1.011	3482	.172	2.196	3720	.368	2.718	3802	.454
	3200	.211	-29.7	3315	.223	1.083	3495	.157	2.424	3727	.321	4.3[illegible]	3810	.412
C-2	3201	.216	-26.5	3315	.223	1.012	3510	.147	[illegible]	3738	.247	1.007	[illegible]	.159
	3208	.238	-26.8	3319	.237	1.000	3513	.147	[illegible]	3841	.237	1.154	3884	.151
D-1	3229	.323	-6.3	3316	.227	2.425	3509	.148	2.278	3737	[illegible]	[illegible].439	[illegible]	.354
	3240	.378	-3.3	3327	.284	2.520	3520	.150	2.107	3743	.231	5.251	3896	.344
D-2	3228	.323	-6.3	3316	.227	2.374	3511	.147	2.311	[illegible]	.243	1.053	3880	[illegible]
	3240	.378	-3.3	3327	.284	2.903	3520	.150	1.027	3746	.227	1.549	[illegible]	.146

Dates are Julian -2440000; V_∞ in emos; declination in degrees; passage radii in planetary radii.

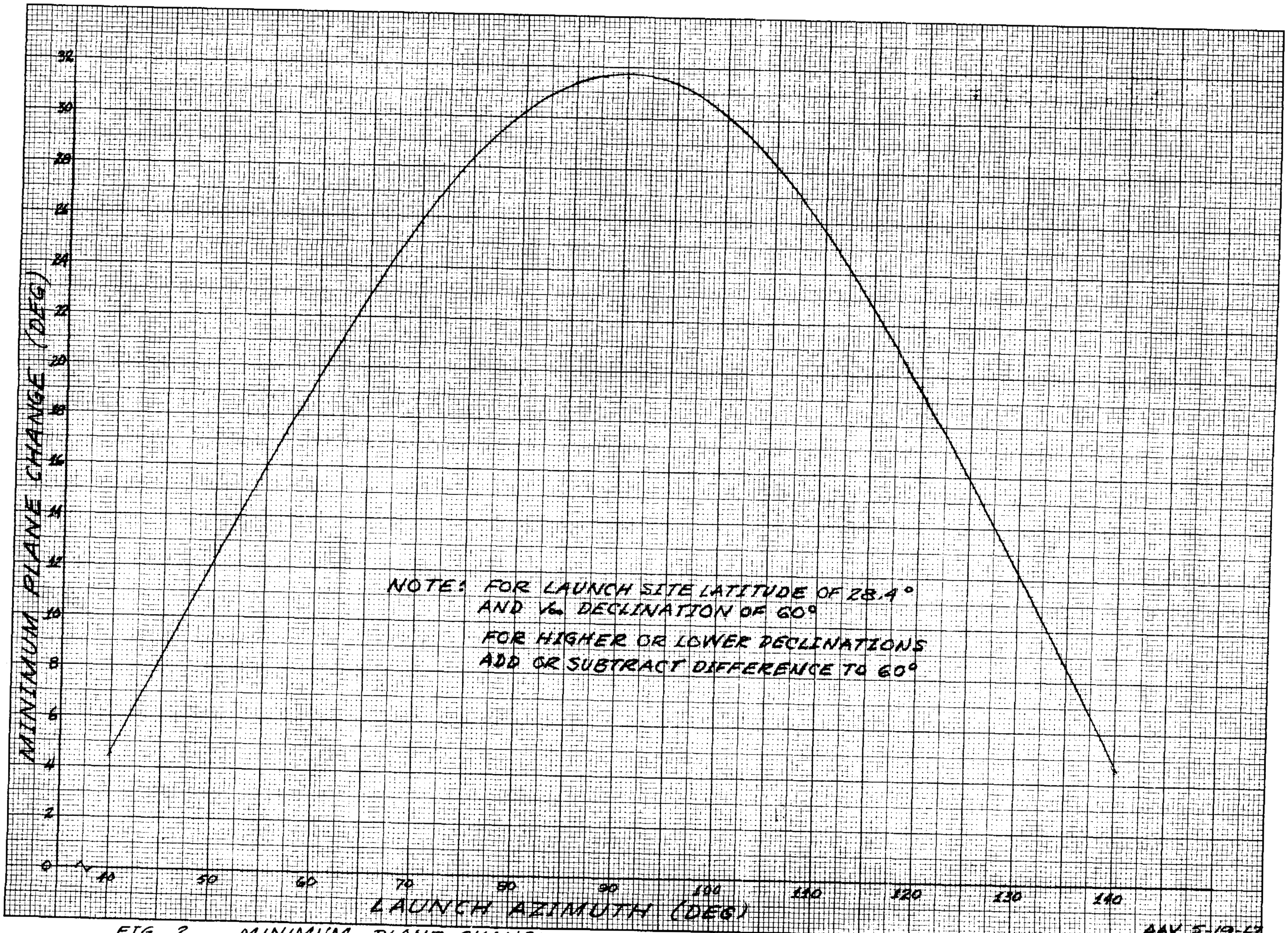

FIG. 2 MINIMUM PLANE CHANGE REQUIRED OUT OF EARTH PARKING ORBIT

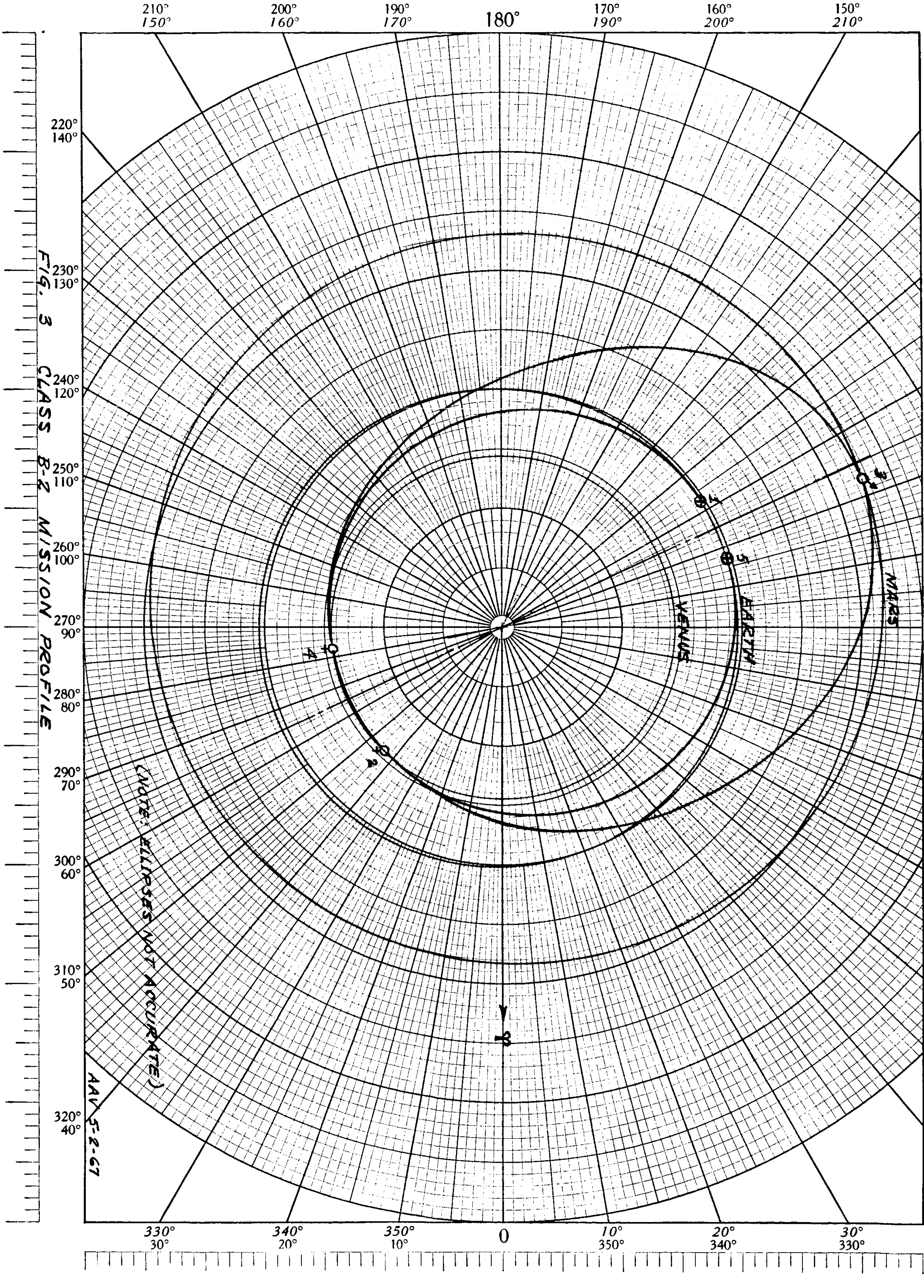
FIG. 3 CLASS B-2 MISSION PROFILE
180°
210° 150°
200° 160°
190° 170°
170° 190°
160° 200°
150° 210°
220° 140°
140° 220°
230° 130°
130° 230°
240° 120°
120° 240°
250° 110°
110° 250°
260° 100°
100° 260°
270° 90°
90° 270°
280° 80°
80° 280°
290° 70°
70° 290°
300° 60°
60° 300°
310° 50°
50° 310°
320° 40°
40° 320°
330° 30°
340° 20°
350° 10°
0
10° 350°
20° 340°
30° 330°
VENUS
EARTH
MARS
1
2
3
4
5
♈
(NOTE: ELLIPSES NOT ACCURATE)
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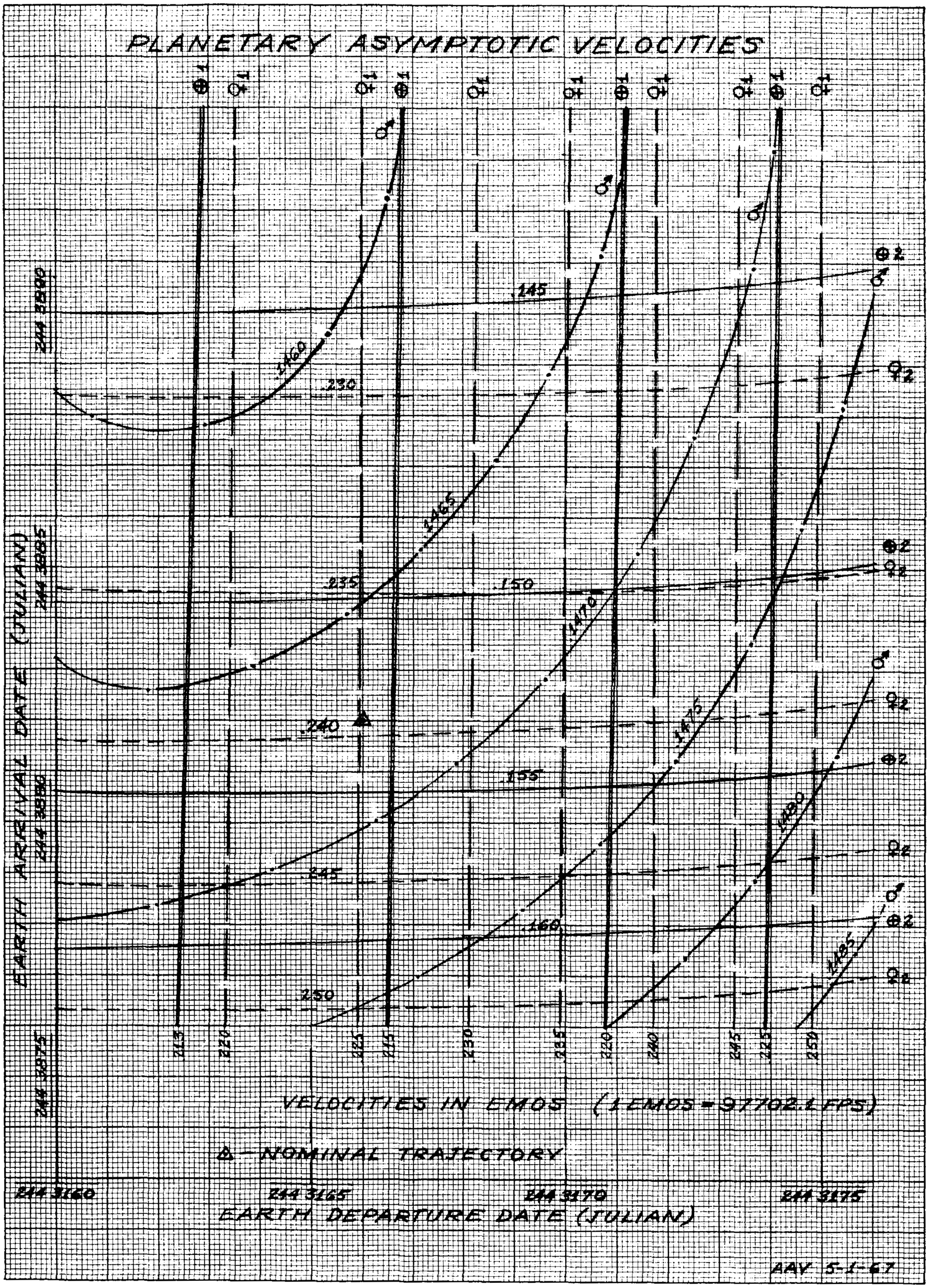

FIG. 4 VELOCITY CONTOURS FOR CLASS B-2 TRAJECTORIES

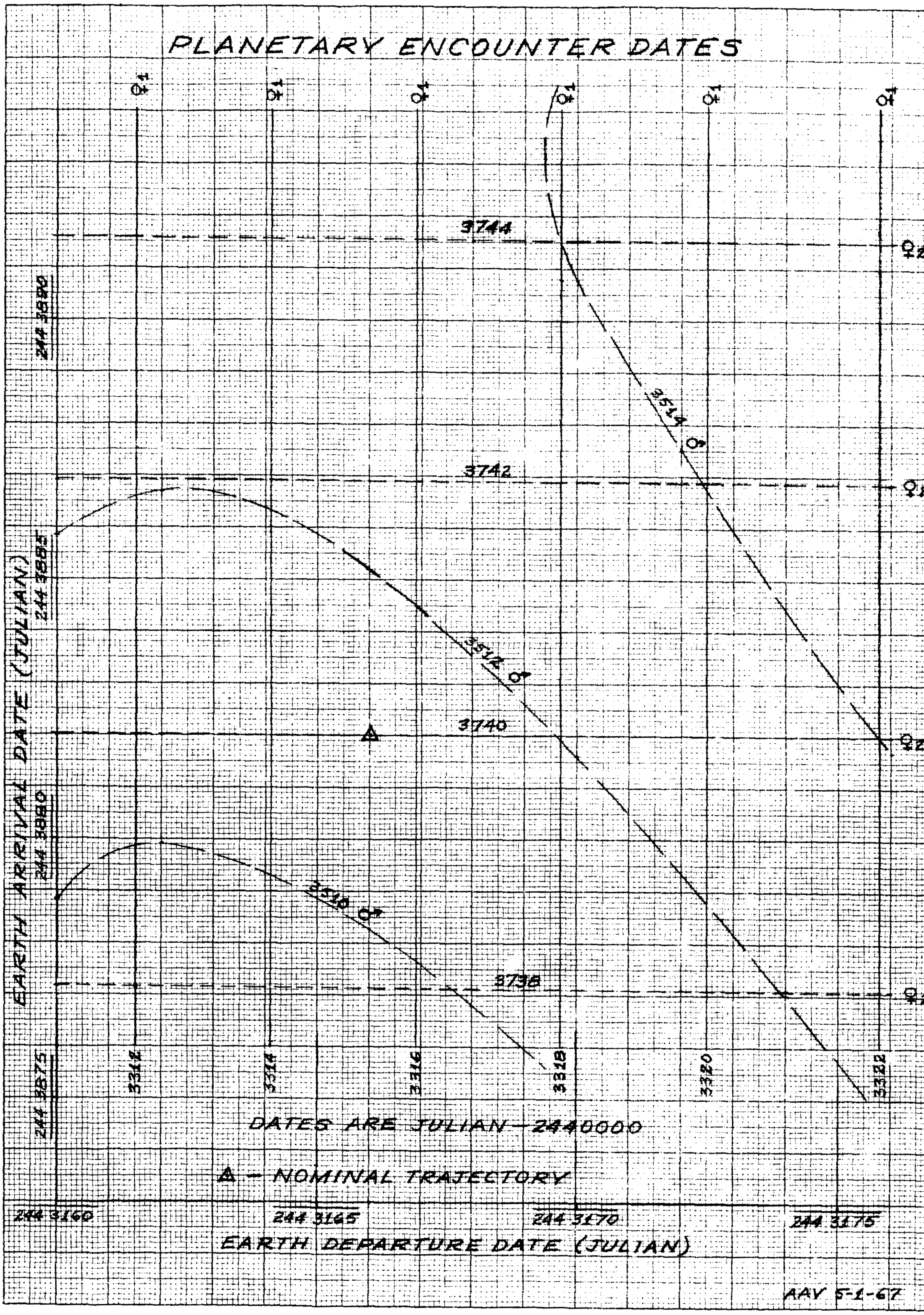

FIG. 5 CLASS B-2 PLANETARY ENCOUNTER DATE CONTOURS

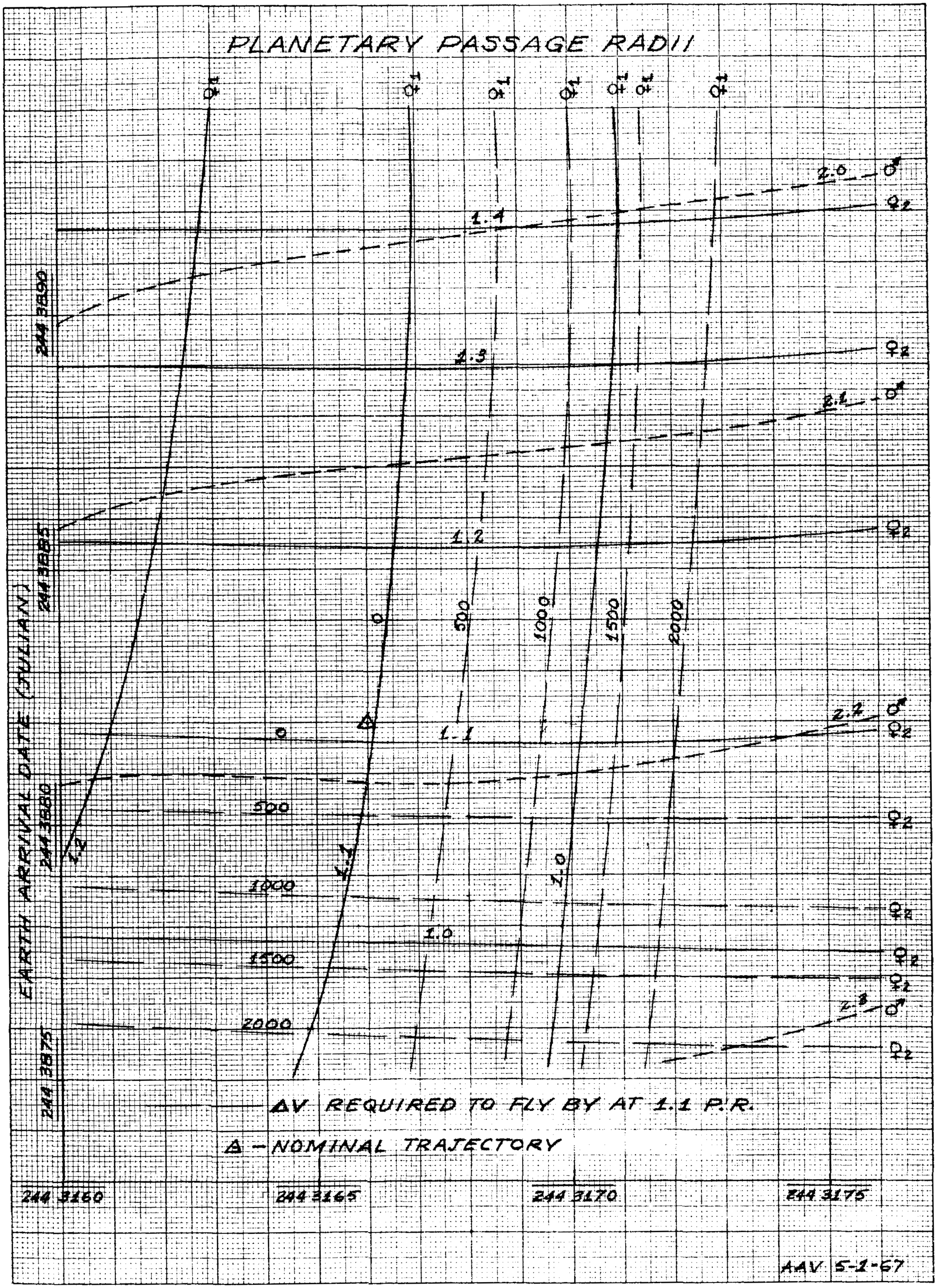

FIG. 6 CLASS B-2 PLANETARY PASSAGE CONTOURS

TABLE 2

PLANET	DATE (JULIAN)	DATE (CALENDAR)	V-INFINITE (EMOS)	INJ., PASSAGE OR ENTRY VEL. (FT/SEC)	DECLIN. OR PASS RADIUS (DEG. OR P.R.)
Earth	244 3166	1/23/77	.2145	16,200	58.9°
Venus	244 3316	6/22/77	.2250	38,900	1.099
Mars	244 3511	1/3/78	.1467	18,200	2.182
Venus	244 3740	8/20/78	.2395	39,700	1.103
Earth	244 3882	1/9/79	.1532	39,200	-28.2°

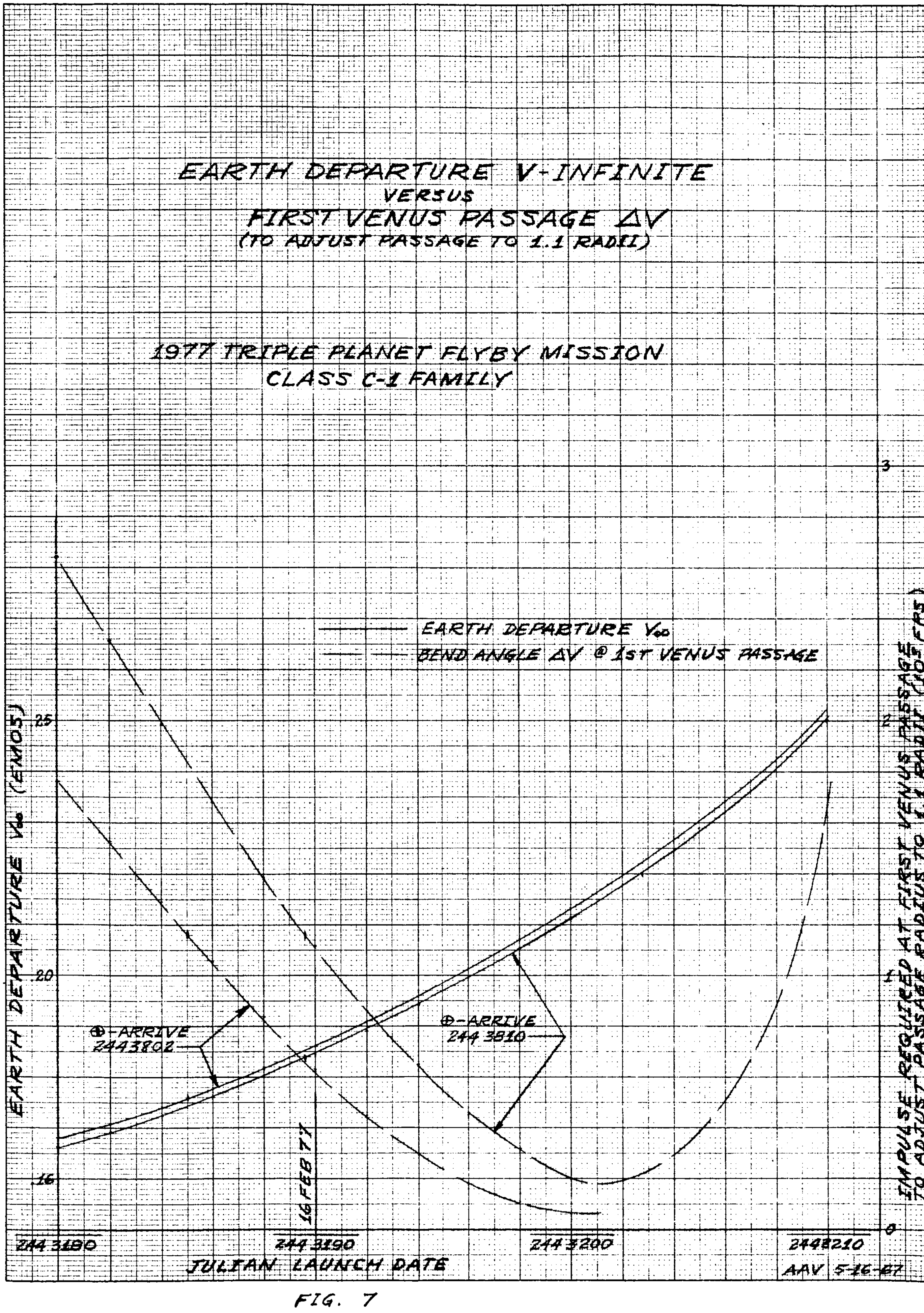
EARTH DEPARTURE V-INFINITE
VERSUS
FIRST VENUS PASSAGE ΔV
(TO ADJUST PASSAGE TO 1.1 RADII)
1977 TRIPLE PLANET FLYBY MISSION
CLASS C-1 FAMILY
EARTH DEPARTURE V∞
BEND ANGLE ΔV @ 1ST VENUS PASSAGE
⊕-ARRIVE 2443802
⊕-ARRIVE 2443810
16 FEB 77
EARTH DEPARTURE V∞ (EMOS)
IMPULSE REQUIRED AT FIRST VENUS PASSAGE TO ADJUST PASSAGE RADIUS TO 1.1 RADII (10⁵ FPS)
25
20
15
3
2
1
0
2443180
2443190
2443200
2443210
JULIAN LAUNCH DATE
AAV 5-16-67

FIG. 7